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Center for Satellite and Hybrid Communication Networks

Modulation, Coding and Interference Cancellation for Satellite Communications

- **Faculty:** E. Geraniotis, A. Ephremides
- **Research Staff:** M. Hadjitheodosiou
- **Graduate Students:** H.J. Su, C.H. Yih, H. ElGamal, M. Khairy, W.C. Chan
- **Industry Support:** M. Gerakoulis (AT&T), K. Etemad (HNS), S. Chuprun (Motorola)
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Support for NASA Missions: Objectives and Significance

- **Objectives:**
  - Increase transmission rate of SATCOM for multimedia applications
  - Increase total capacity (number of circuits supported) and total throughput (Mbps) of SATCOM communication
  - Guarantee low BERs for multimedia services while satisfying time-delivery requirements
  - Lower transmitted power and antenna size requirements
  - Mitigate/eliminate in-band interference to alleviate power, size requirements and coexistence/proximity
- **Significance:**
  - Higher throughputs and transmission rates can be provided for ISS to Earth communication
  - Higher throughputs and transmission rates can be supported for communication between ISS and LEO/MEO/GEO satellite networks
  - Higher transmission rates possible for Deep Space missions
  - Smaller antenna sizes needed for both earth stations and spacecrafts or satellites
  - Smaller size, weight and power of SATCOM terminals

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Commercial Objectives and Significance

- **Objectives:**
  - Increase transmission rate of SATCOM for multimedia applications
  - Increase total capacity (number of circuits supported) and total throughput (Mbps) of SATCOM communication
  - Guarantee low BERs for multimedia services while satisfying time-delivery requirements
  - Lower transmitted power and antenna size requirements
  - Mitigate/eliminate in-band interference to alleviate power, size requirements and coexistence/proximity
- **Significance:**
  - Higher throughputs and transmission rates enabled
  - More subscribers served
  - Additional multimedia services offered
  - Greater coverage provided
  - Transmitted power and antenna size requirements lowered
  - Increased on-board processing and switching capabilities enabled
  - More satellite networks can co-exist (proximity issues)
  - Reception reinforcement (inside buildings)
  - Reliable broadcast/multicast to users with different reception capabilities

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Areas of Research Focus

- Techniques for almost coherent demodulation in SATCOM inbound Links
- Turbo codes and iterative decoding for satellite communications
- Turbo TCM (Trellis-Coded Modulation) for M-PSK and M-QAM for high data rate SATCOM
- Adaptive closed-loop power control for SATCOM
- Adaptive coding and adaptive modulation for rain fades
- Asymmetric modulation and coding for Broadcast/Multicast SATCOM
- Unequal error protection for Multicast SATCOM with multi-level reception capabilities

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Areas of Research Focus (Cont.)

- **Diversity combining with iterative decoding for SATCOM signals**
- **Joint diversity combining and handoff for SATCOM signals**
- **Interference Suppression**
  - Co-channel interference mitigation (for TDM-, FDM- and OFDM-based SATCOM systems)
  - Adjacent-channel interference mitigation (for TDM-, FDM- and OFDM-based SATCOM systems)
  - Other-user interference suppression/Multi-user detection (for CDMA-based SATCOM systems)

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Applications/Funded Projects (Last 4 years)

- **Soft handoff and dual satellite (diversity) combining for LEO SATCOM (Globalstar/Loral)**
- **High Data Rate GEO SATCOM Network: VoiceSpan (K_u FCC Filing by AT&T)**
  - SE/CDMA modem design
  - Earth station (hub) design
  - On-board signal processor design
  - On-board CDMA switch design
- **DS/CDMA modem design for GEO SATCOM (TSI Inc.)**

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Applications/Funded Projects (Last 4 years) (Cont.)

- DS/CDMA modem and earth station design for Navy fleet SATCOM (NRL)
- Multi-level reception for broadcast/multicast SATCOM (ONR)
- Digital Audio Broadcast Satellite Systems (DABS) design [WorldSpace Manag. Inc (TDMA), CD Radio Inc (CDMA).]

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Almost Coherent Demodulation for Inbound SATCOM Links

- **Issue: Coherent demodulation in inbound SATCOM links is impaired by**
  - Channel fading
  - Doppler frequency shift (for mobile terminals)
- **Solution/Our Approach: Pilot-aided or symbol-aided demodulation (PAD or SAD) with iterative decoding**
  - Use pilot signals or insert (periodically) known symbols during transmission
  - Estimate channel amplitude and phase from pilots or known signals; use filtering and smoothing
  - Extrapolate amplitude/phase estimates for unknown symbols from above estimates of known symbols
  - Use iterative decoding (feedback soft decoder outputs to above filters) to enhance estimation accuracy
  - Demodulate (almost coherently) the unknown symbols using the enhanced channel estimates
  - Use approach for both convolutional and Turbo codes
  - For fast fading (large Doppler) use MDD (multiple differential detection) coupled with iterative decoding

High-Order Modulation for High Data Rate SATCOM

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- **Goal: Increase spectral efficiency (bits/sec/Hz) through use of high-order modulation (M-PSK or M-QAM) while still guaranteeing low BER**
- **Difficulties:**
  - M-QAM is more power efficient than M-PSK but suffers more from nonlinear distortion introduced by transponder amplifiers
  - M-PSK and M-QAM have worst BER (bit error rate) than BPSK or QPSK
- **Solution/Our Approach: Turbo Trellis Coded Modulation (TCM) and iterative decoding**
  - Use of Turbo TCM guarantees low BERs for M-PSK and M-QAM
  - Combine pre-distortion techniques with iterative decoding for mitigating nonlinear effects
  - Use Turbo equalization to suppress effectively ISI
  - For delay-sensitive traffic (voice), use TCM with convolutional (not Turbo) codes; retain iterative decoding for nonlinearity mitigation and equalization

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Turbo Codes for SATCOM Applications

- Goal: Lower the transmitted power (or use smaller size antenna) through the use of more powerful FEC (Forward Error Control Codes) such as Turbo Codes
- Difficulties: Additional processing delay of Turbo codes prevents their use for delay-sensitive traffic (e.g., voice)
  - Turbo codes use internal interleaver (introduces buffering delay)
  - Turbo codes use iterative decoding (decoding delay proportional to number of iterations)
  - For fading channels Turbo codes lose some of their advantage over convolutional codes

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Turbo Codes for SATCOM Applications (Cont.)

- **Solution/Our Approach: A new class of Turbo codes that require shorter internal interleavers; decoding algorithms that minimize number of required iterations**
  - Use special interleaver design based on block codes
  - Use search decoding strategy rather than MAP or log-MAP decoding
  - Our approach works with both Parallel and Serial Concatenated Convolutional Codes (PCCC and SCCC architectures of Turbo codes)
  - Our Turbo codes do not exhibit an error floor
  - Our codes (with an 70- to 80-bit interleaver) outperform standard Turbo codes (with 1000-bit interleaver) for E_b/N_0 's larger than 2.5 dB and BERs lower than 10^{-5} [for AWGN channel]
  - For fading channels, modify Viterbi, MAP, or search decoding metrics to account for fading statistics

New Interference Suppression Techniques for SATCOM Applications

- **Goal: Mitigate in-band interference present at terminals and earth stations of SATCOM systems**
- **Difficulties:**
  - Signal processing power at terminals is limited
  - Real-time/delay-sensitive traffic can not tolerate delay introduced by excessive processing
  - Signals that must be cancelled may be (fully or partially) unknown and must be estimated
  - Received powers of signals may vary significantly

New Interference Suppression Techniques for SATCOM Applications (Cont.)

- **Solution/Our Approach: Use recent advances in multi-user detection and signal separation techniques coupled with the iterative decoding principle of Turbo codes**
  - For co-channel interference mitigation (TDM, FDM or OFDM systems) use a combination of subspace separation, oversampling and identification techniques coupled with soft decoder output feedback
  - For adjacent-channel interference mitigation (TDM or FDM systems) use filtering and channel identification coupled with iterative decoding
  - For other-user interference cancellation (CDMA systems) use iterative decoding to assist both an MMSE-based other-user interference canceller and the (pilot- or symbol-aided) estimator of the channel amplitudes and phases of all users
  - Variants of our approach are applicable to scenarios where some but not all of the signals to be cancelled are demodulated and decoded